EARTHS IN OTHER SOLAR SYSTEMS: FUNDAMENTAL DISK PROPERTIES AND THEIR EVOLUTION.

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Introduction: Earths in Other Solar Systems (EOS) is a NASA-funded five-year interdisciplinary exoplanet research program aiming at understanding how and where habitable planets form (PI, D. Apai). EOS is also part of the NASA Nexus for Exoplanet System Science. EOS has four main objectives that focus on tracing the evolution of volatiles and organics from star-forming regions into protoplanetary disks, planets, and Solar System bodies like meteorites and comets.

In this contribution we will give an overview of our EOS Objective 2: *How are volatiles and organics processed in protoplanetary disks?* We will discuss results from our surveys of protoplanetary disks that aim at establishing how fundamental properties such as disk masses, disk lifetimes, and stellar accretion rates change as a function of age and stellar mass. We will also present intial results on the distribution of the main molecular carriers of C, H, and N in disks. Finally, we will present state-of-the art chemical and physical models of disks that trace the evolution of gas and dust.

Methods: We targeted protoplanetary disks in star-forming regions, from low-mass to rich clusters, of different median ages at optical and millimeter wavelengths. Optical spectroscopy was used to homogeneously re-classify stars and measure mass accretion rates while millimeter interferometry yielded disk masses. High-resolution (R~10km/s) optical and infrared spectroscopy was carried out on a sub-sample of disks to identify bound vs non-bound material and determine the radial extent of volatiles and organics. Disk models couple the dynamical and chemical evolution of protoplanetary disks wth focus on the planet-forming region.

Results: Our optical and millimeter surveys of protoplanetary disks demonstrate that the dust disk mass-stellar mass scaling relation is steeper than linear and further steepens with age (see Figure 1, [1]). Similarly steep relationships are found between mass accretion rates and stellar masses [2,3]. We are in the process of expanding our Orion millimeter survey [4,5] to measure dust disk masses at even younger ages for a rich stellar environment. Optical high-resolution spectroscopy identified a new and more direct diagnostic of MHD-driven disk winds and demonstrates that such winds are common in Myr-old disks [6]. We also have tentative evidence for an evolution in disk winds with the possible disappearance of the MHD-driven component as the inner disk clears out. Our high-resolution mid-infrared spectroscopy of a few disks finds that water and other organics trace gas at terrestrial planet forming radii [7]. These observations are critical to properly interpret lower resolution but more sensitive infrared spectroscopy that can be carried out with JWST. Our disk models demonstrate the importance of dynamical effects in setting the location of the water snowline [8]. We will conclude by providing a revised view on habitable planet formation guided by these findings and will discuss how these new observational constraints inform other objectives within EOS.

References: [1] Pascucci I. et al. (2016) *ApJ, 831, 125*. [2] Manara et al. *ApJ submitted*. [3] Mulders et al. *in prep*. [4] Eisner J. et al. (2016) *ApJ, 826, 16*. [5] Fang, M. et al. (2016) *in prep*. [6] Simon M. et al. (2016) *ApJ, 831, 169*. [7] Najita J. et al. *in prep*. [8] Krijt et al. (2016), *ApJ, 833, 285*.

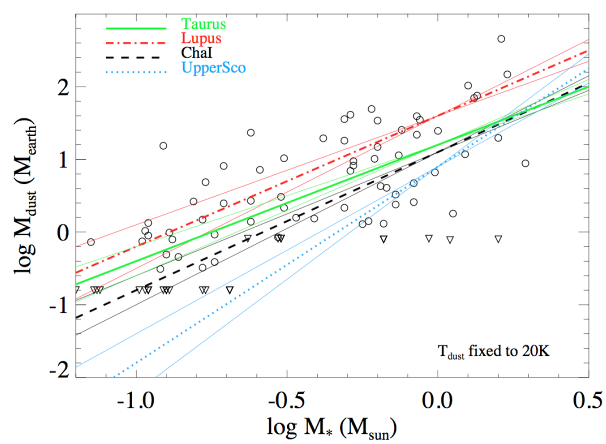

Figure 1: Dust disk mass-stellar mass relation in four different regions, from [1]. Note that the ~10Myr-old Upper Sco association has a stepper relation than the other three younger star-forming regions.